Transients from all sky observed by INTEGRAL

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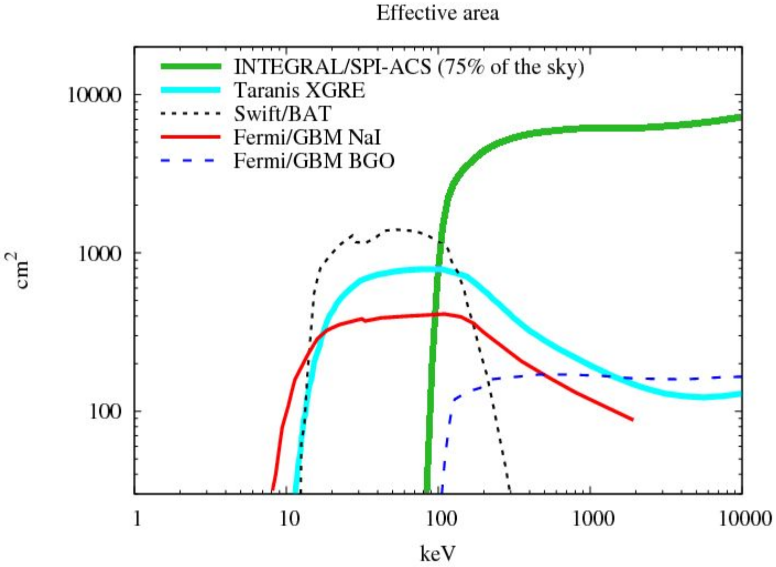
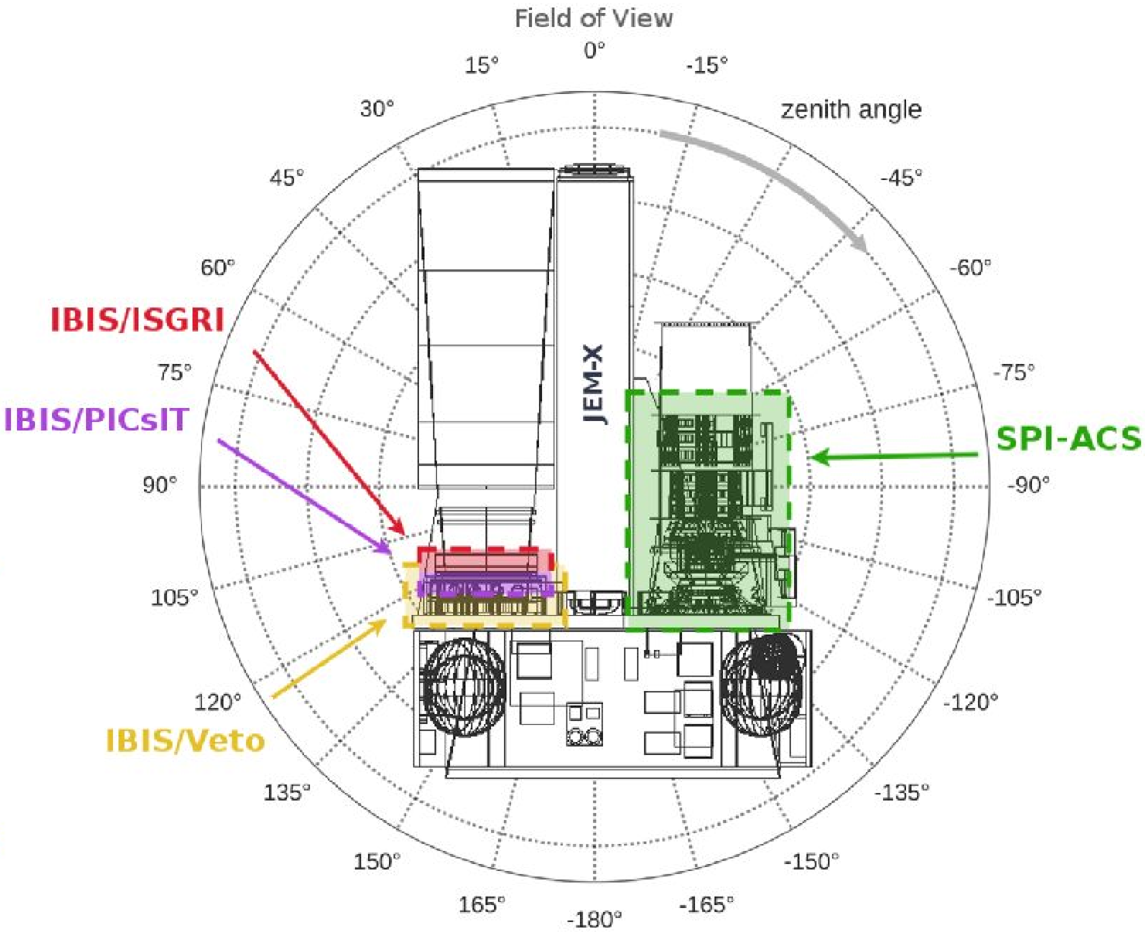
IUG meeting 2017
ESTEC, Nordwijk

Substantial fraction of the **INTEGRAL** mass is detectors

>~100 keV - gamma rays are stopped by substantial mass: they typically reach active medium: principal detectors or active shields





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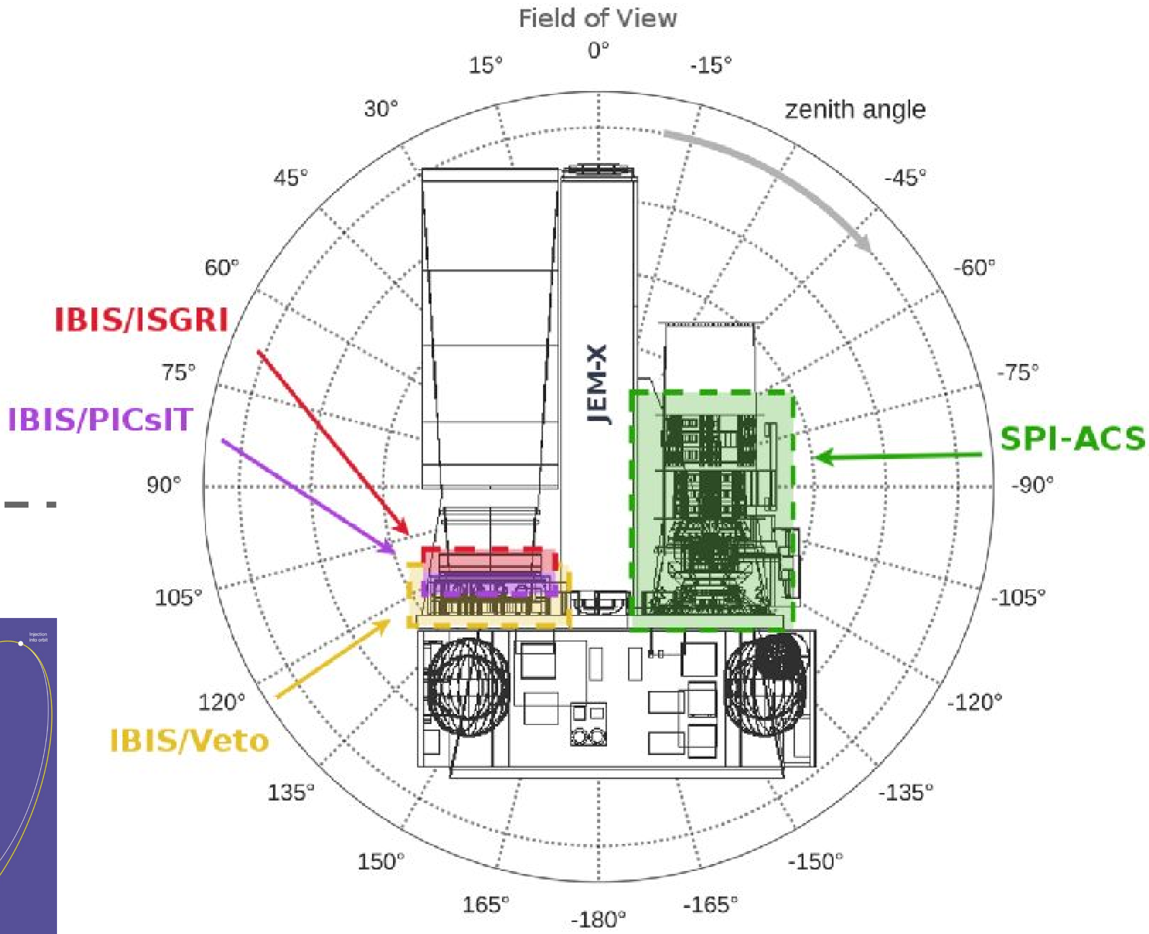
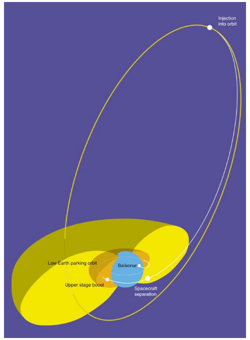


No Earth shadow!

Compare to Fermi/GBM: coverage about 65% at any given moment



Challenges of the all-sky observations

Characterizing the **background**

Distinguishing various particle effects is vital for **event detection**

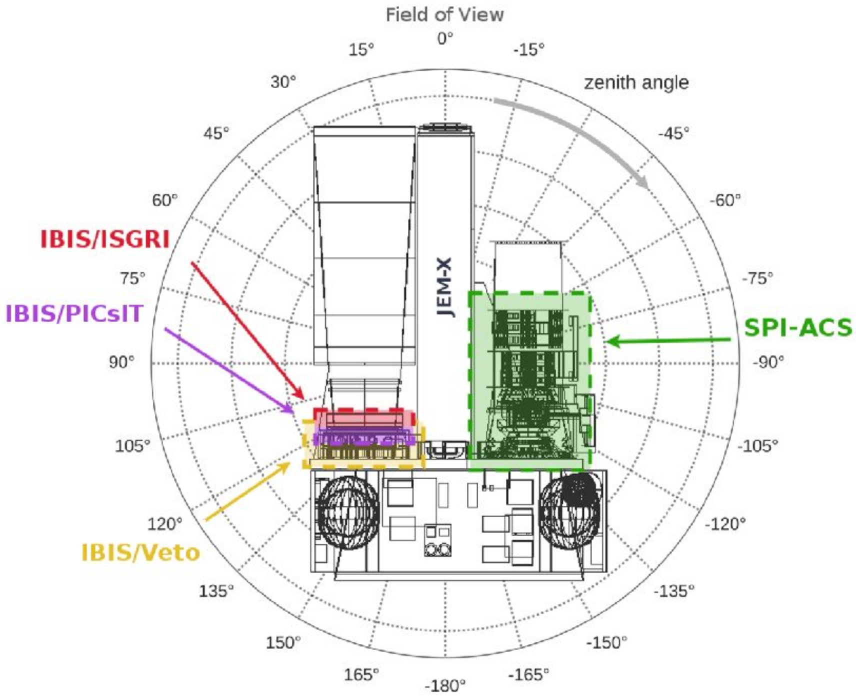
Computing, verifying the **response**

the electronics in non-standard modes: thresholds, multiple events, etc.

opacity structure: passive and active media

Non-standard use of the detectors needs verification

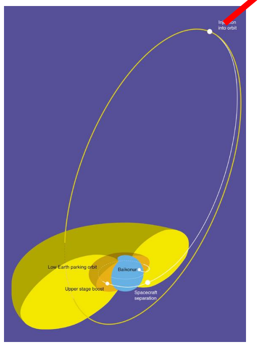
cross-calibration in collaboration with other teams is the key to successful event **detection and characterization**

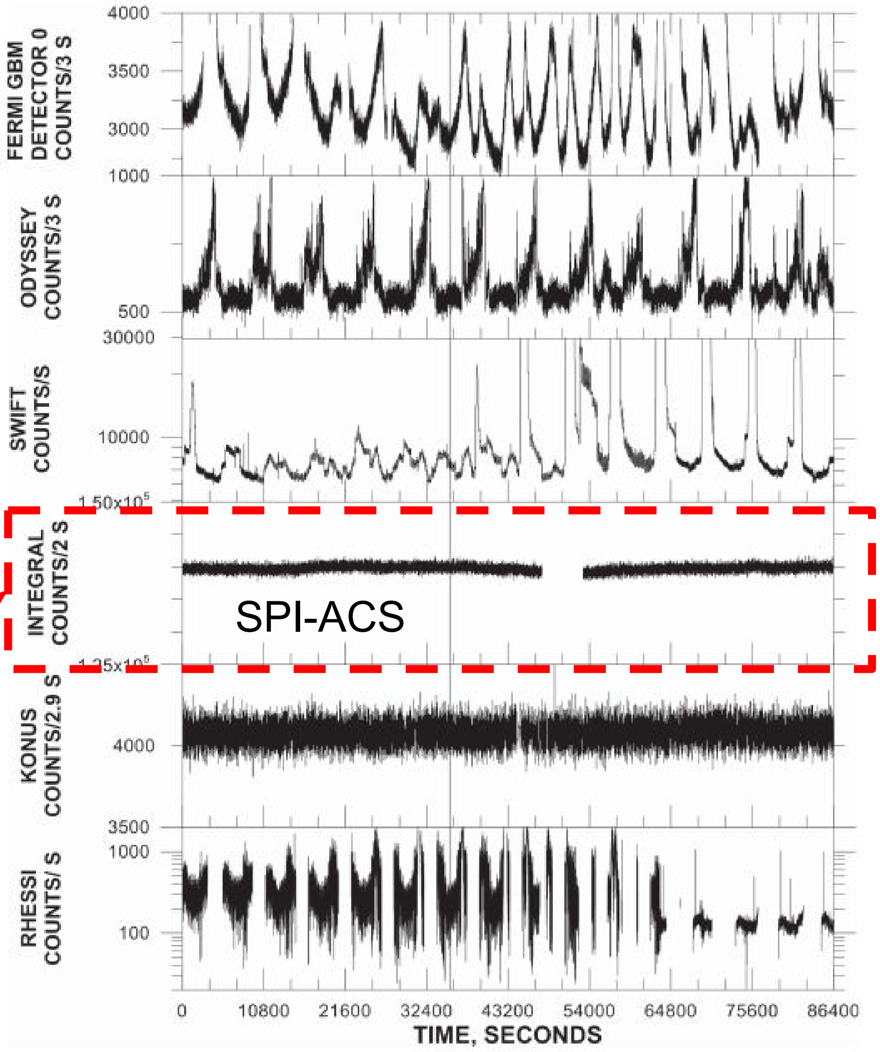


Background

Owing to very elongated orbit, INTEGRAL features typically **stable background** on scale of 2 days.

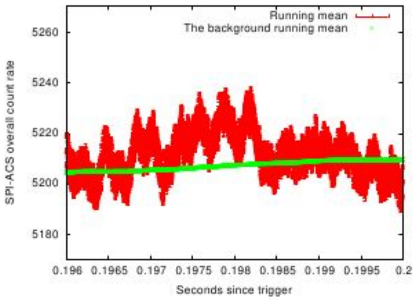
Enhanced high particle flux is a mild disadvantage.



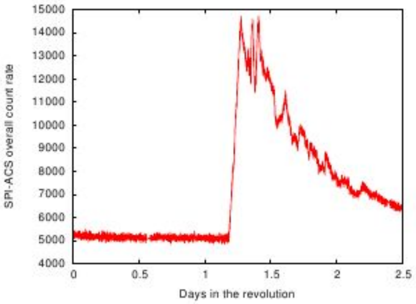


Hurley et al 2016

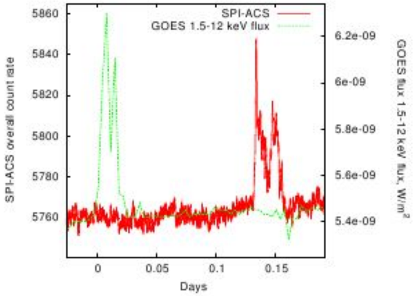
Background: solar activity in SPI-ACS



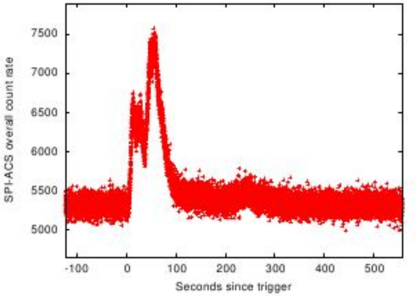
(a) Weak solar activity



(b) Very bright flare



(c) Isolated proton flare and the GOES data



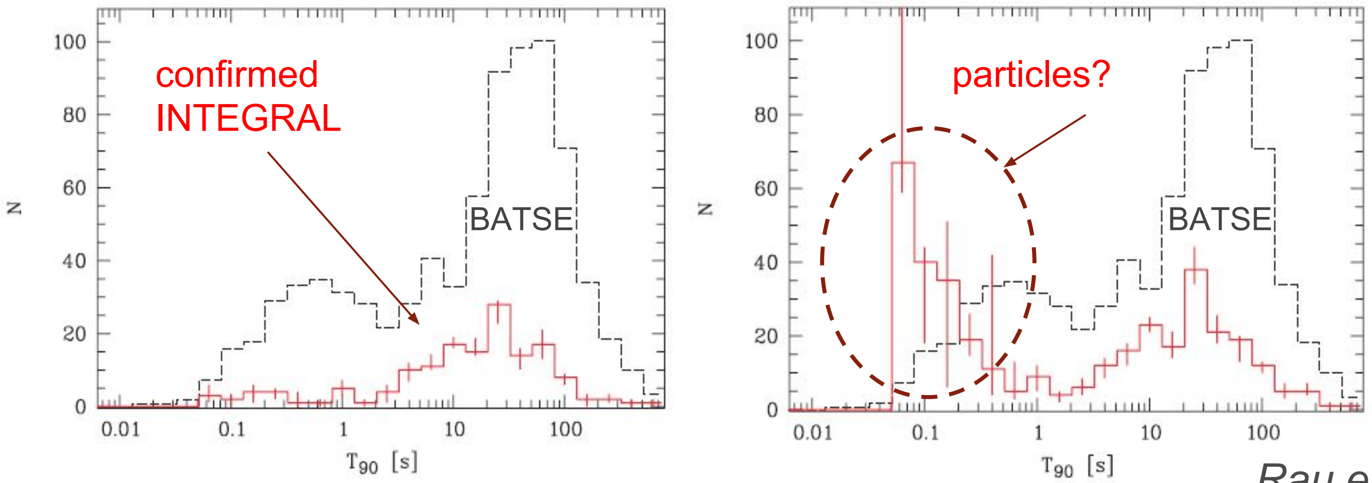
(d) Similar to a GRB

Solar flares introduce various effects in the SPI-ACS data, contributing to the background for GRB searches.

Usually stability of the background around the GRB can be used to exclude affected regions.

This in the limitation for long burst detection.

Background: particles in SPI-ACS



Rau et al 2005

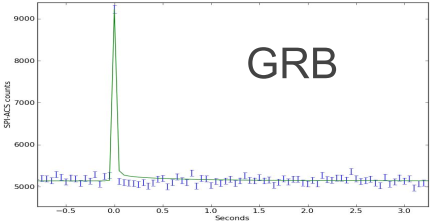
The first catalogue of INTEGRAL all-sky GRB transients in 22 months of SPI-ACS data.

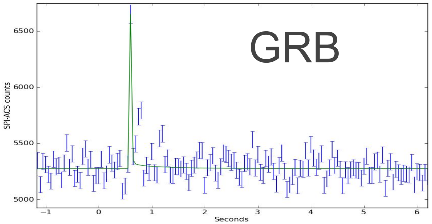
Large number (30/day) of very short events - “the short spikes” was attributed to the high-energy cosmic ray interaction effects but could not be separated with INTEGRAL alone

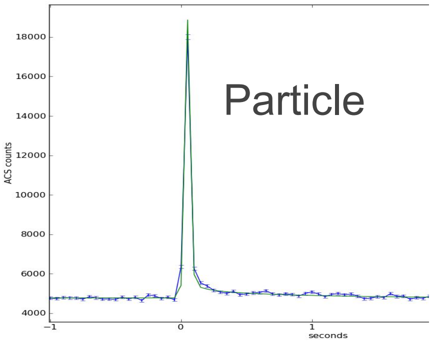
Background: particles in SPI-ACS

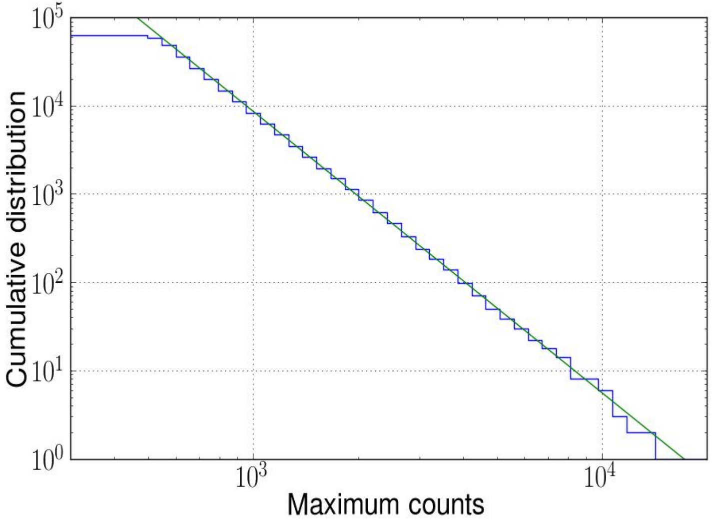
The expected shape is universal: all the spikes are renormalized template.
This can be used to exclude them.

~100 000 short spikes rejected







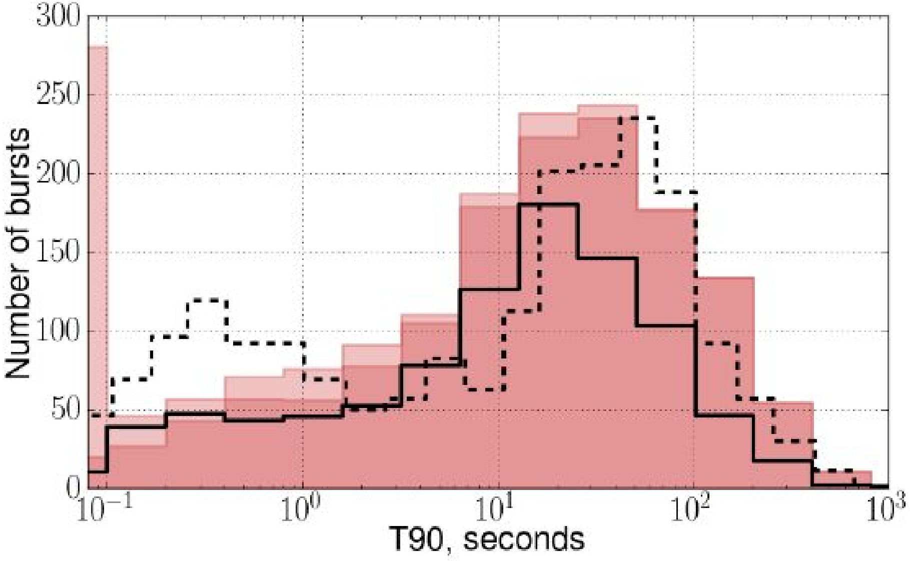


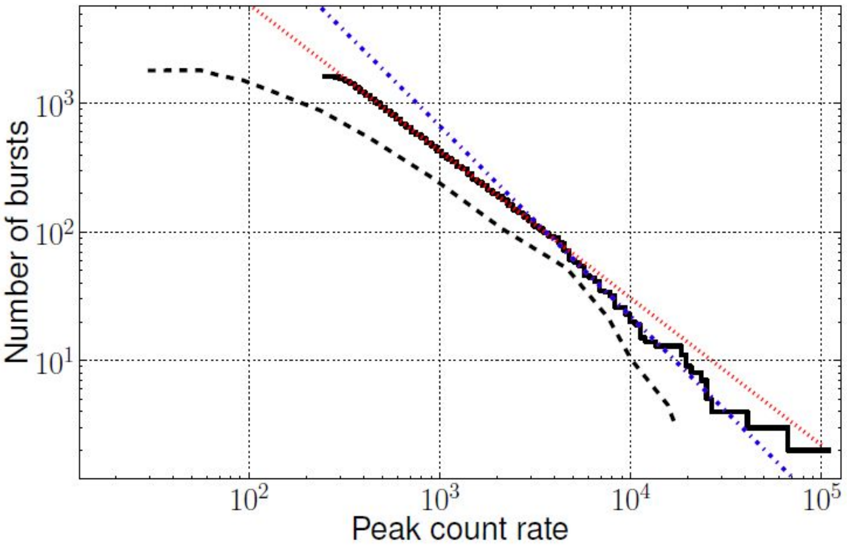
VS12

Even rather weak real bursts may not be rejected.

Even very bright events may fit the template.
The distribution of the peak count rates is very regular.

Second SPI-ACS trigger catalogue



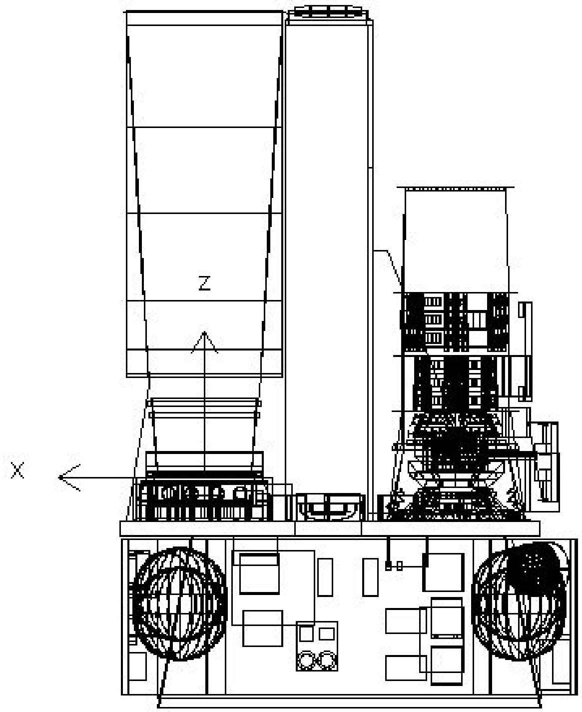


The SPI-ACS o**ffline pipeline is regularly used** to identify possible transients independently and in coincidence with various events

SPI-ACS response

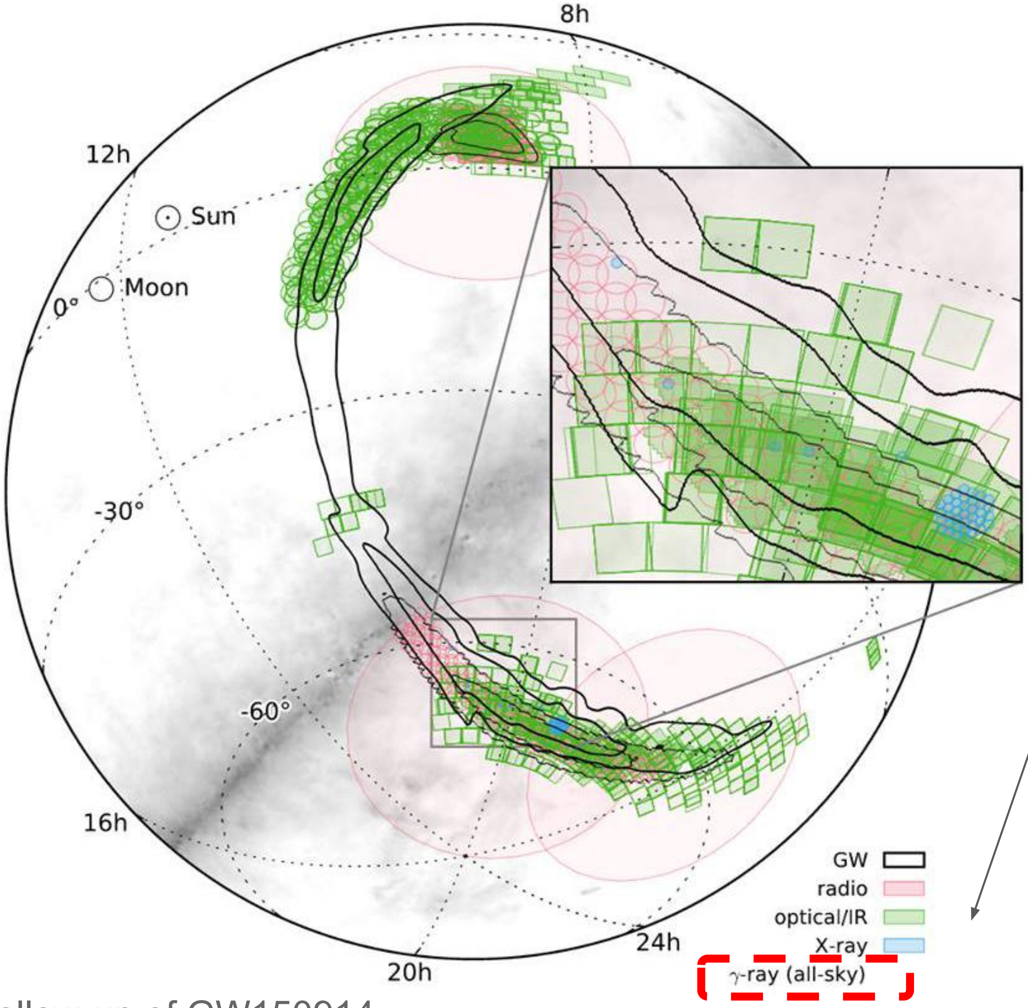
Understanding the performance of the detection pipeline is critical to reliably report detections

But in order to compare SPI-ACS detections with other instruments the mass models (SPIMM and TIMM) were verified using bright and hard bursts and then used in a number of publications.



The mass model

Electromagnetic Follow-up of GW

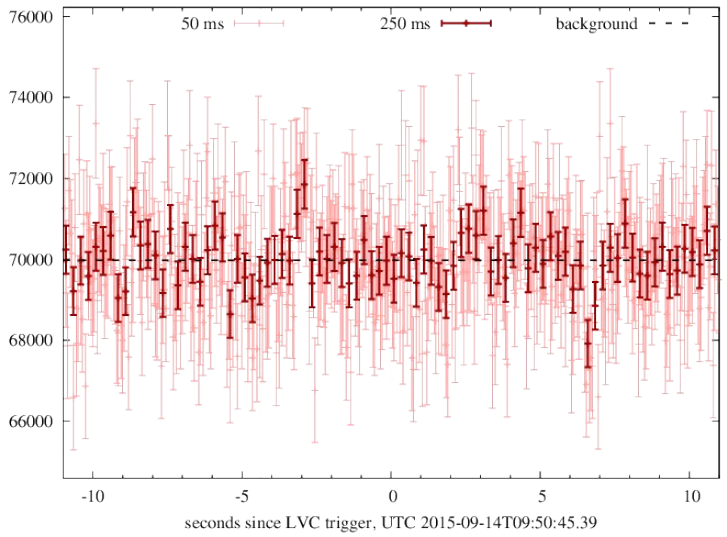


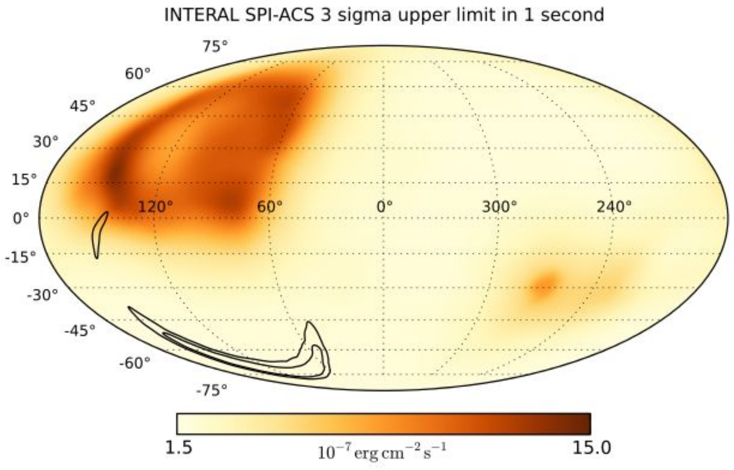
Follow-up of GW150914

The GW events localizations are extended

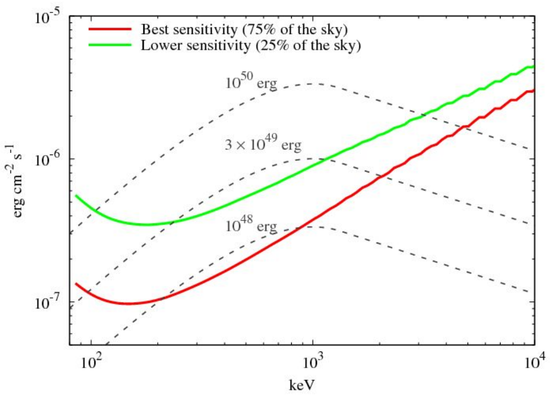
Only INTEGRAL, and Konus-Wind (albeit with lower sensitivity) have true instantaneous all-sky coverage

GW150914: upper limit



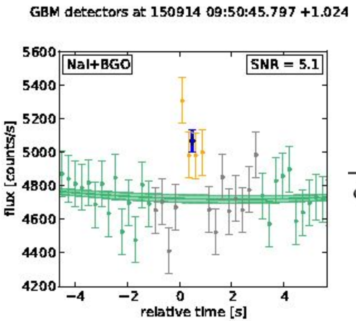


10^{-6} - ratio of energy in 75-2000 keV to GW



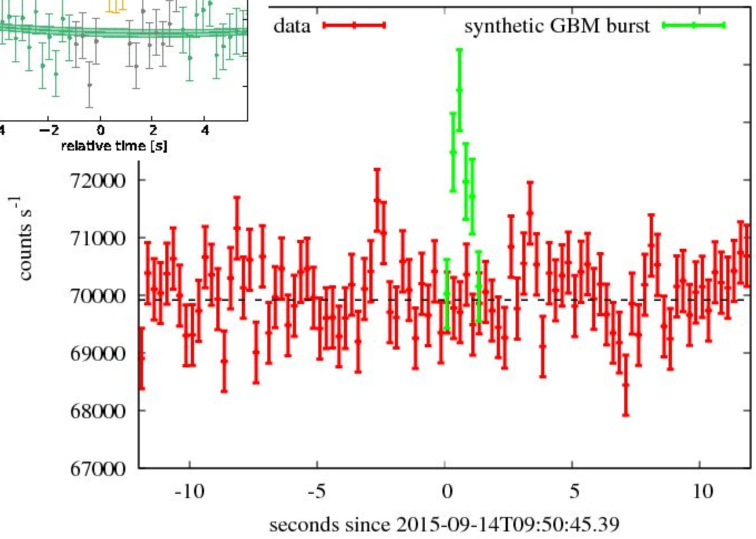
The region was in a very lucky orientation for SPI-ACS! Lucky background conditions too.

And Fermi/GBM



Connaughton et al 2016

It’s complicated...



Rescaling real GRB with a moderately hard spectrum assuming **best fit fluence of GBM-GW150914,** resulting in **15 sigma** detection: **good margin**!

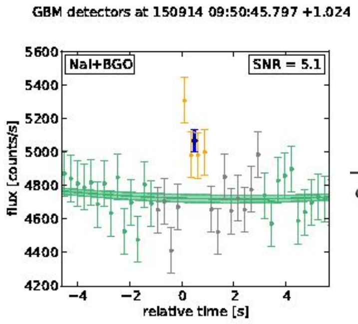
Some spectra, soft and weak, could be marginally compatible with SPI-ACS and GBM data, but **the probability is likely very low**

But, given that the the excess in Fermi/GBM is limited to high energy, soft spectrum implies no detection.

Greiner et al 2016

Fully taking into account statistical and systematic uncertainties in the GBM parameter estimation is required. The collaboration is ongoing, **useful for future observations**!

And Fermi/GBM (2.9 sigma)



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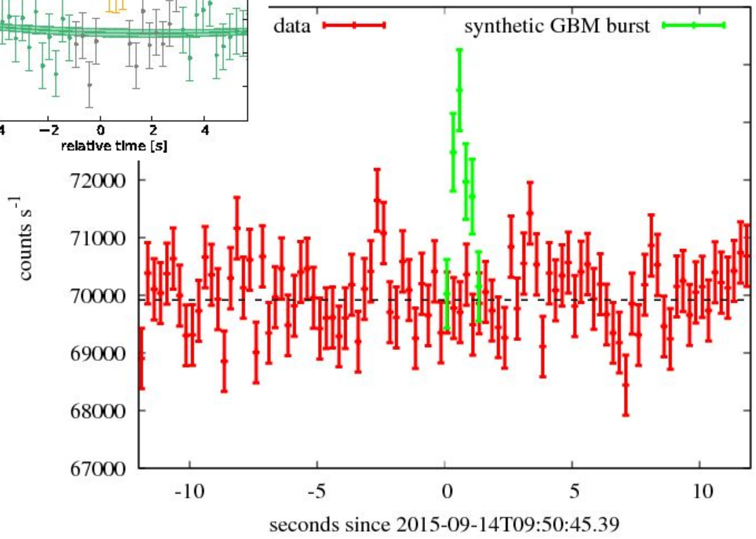

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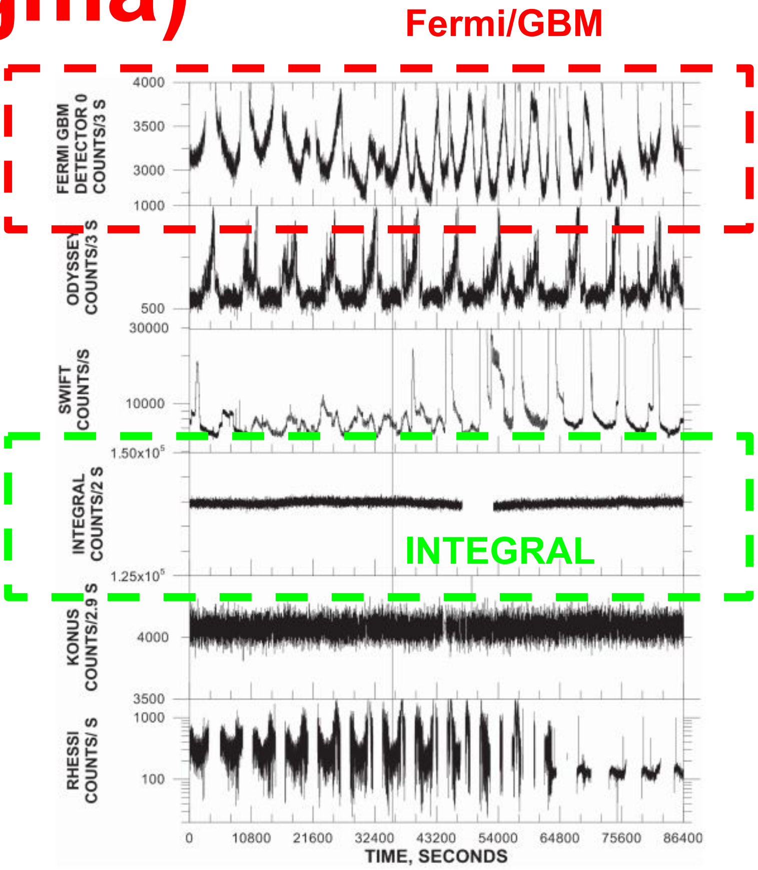
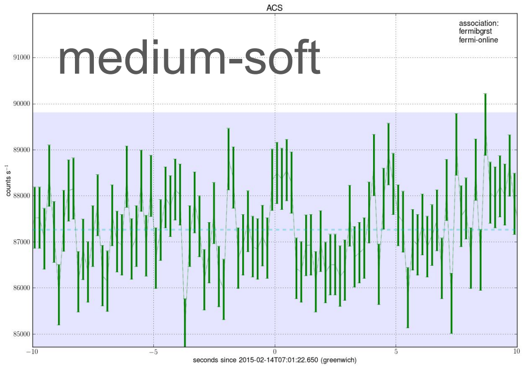
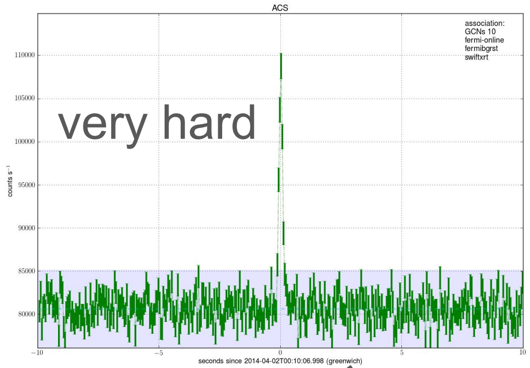


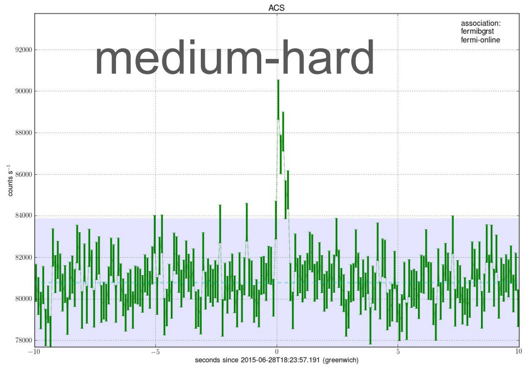
Note variations of the Fermi/GBM background on all time scales, resulting in large FAR

Fermi/GBM sGRB with fluence similar to GBM-GW

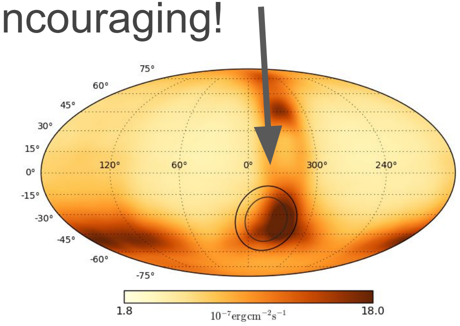
Typical GRBs of the same fluence are compatible between Fermi/GBM and INTEGRAL/SPI-ACS: **understanding of the intercalibration is encouraging!**

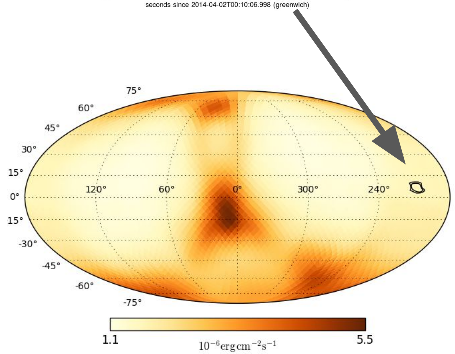


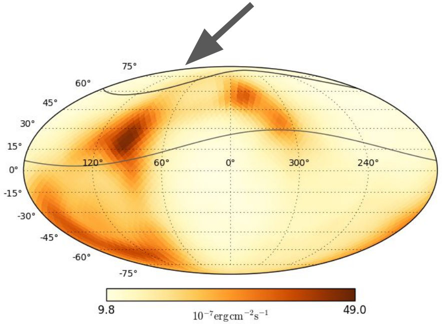




encouraging!





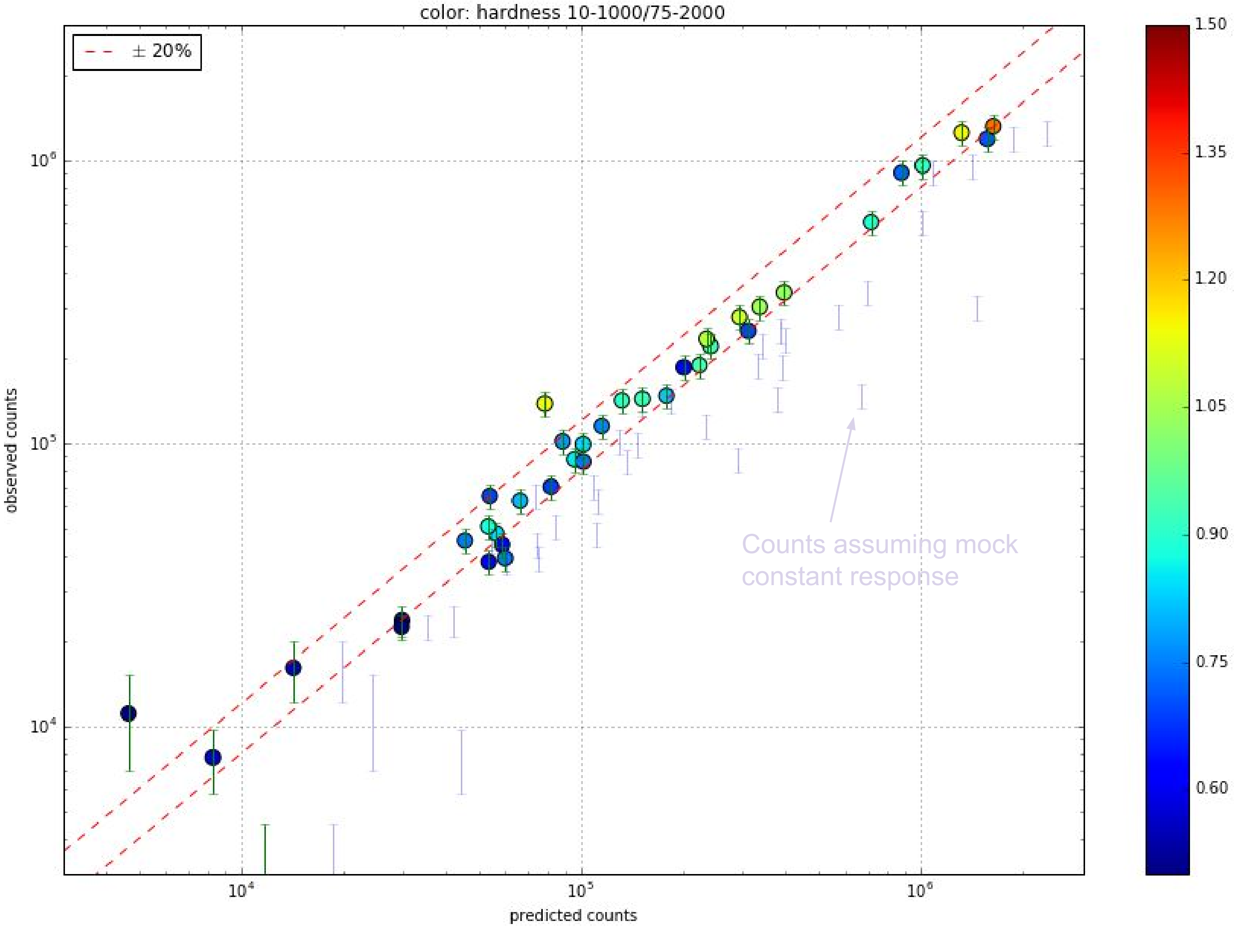


SPI-ACS - Fermi/GBM cross-calibration

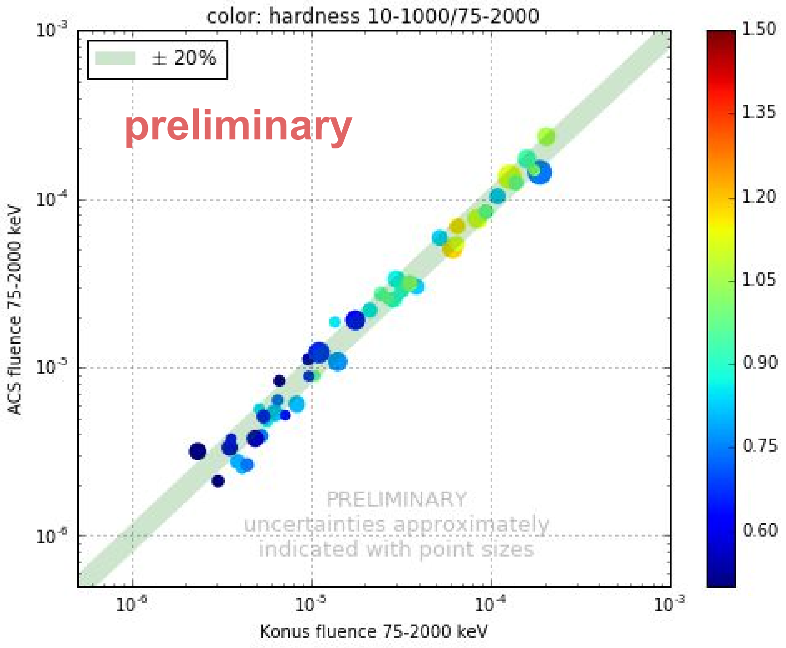
INTEGRAL SPI-ACS response based on mass model was calibrated on bright and hard well-characterized GRBs.

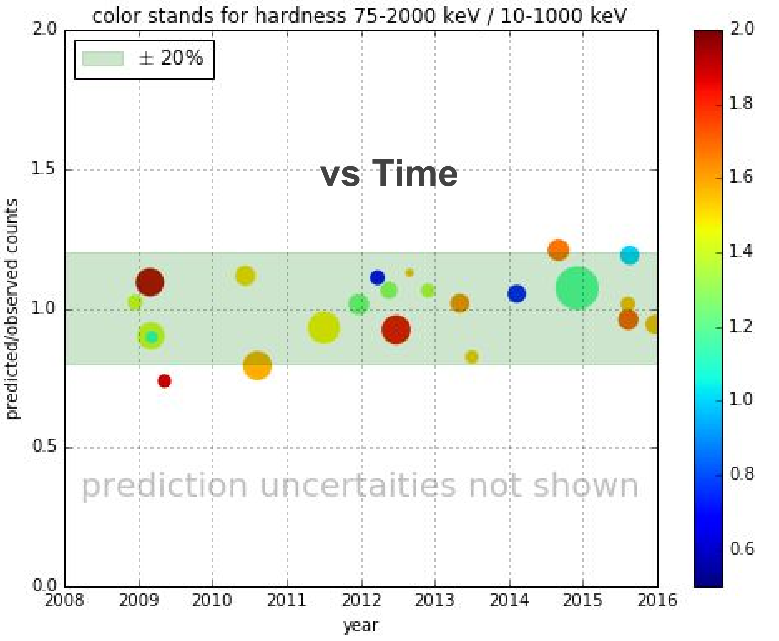
The response was then further verified with Fermi/GBM GRBs of a large range of spectral properties.

The response can be securely applied to weak bursts of comparable spectra.



Cross-calibration
dependency on spectrum, intensity, time





INTEGRAL/SPI-ACS - Konus-Wind: verification with detailed private Konus spectra reveal consistent picture

Status of Fermi/GBM vs INTEGRAL discussion

The original event had a **significance of association with GW of 2.9 sigma** - because of **high rate of GBM background fluctuations**

The **SNR** of the event reported by *Connaughton et al 2016* is **~5**, with a fluence of ~2 x 10^{-7} erg cm^{-2} in 10 - 1000 keV (not clearly reported) - not too weak, but in an unusual orientation for Fermi/GBM - from the bottom.

Bursts of this fluence level are securely (up to 28 sigma) detected by INTEGRAL/SPI-ACS, given the right location and spectrum, **compatible with the response model**.

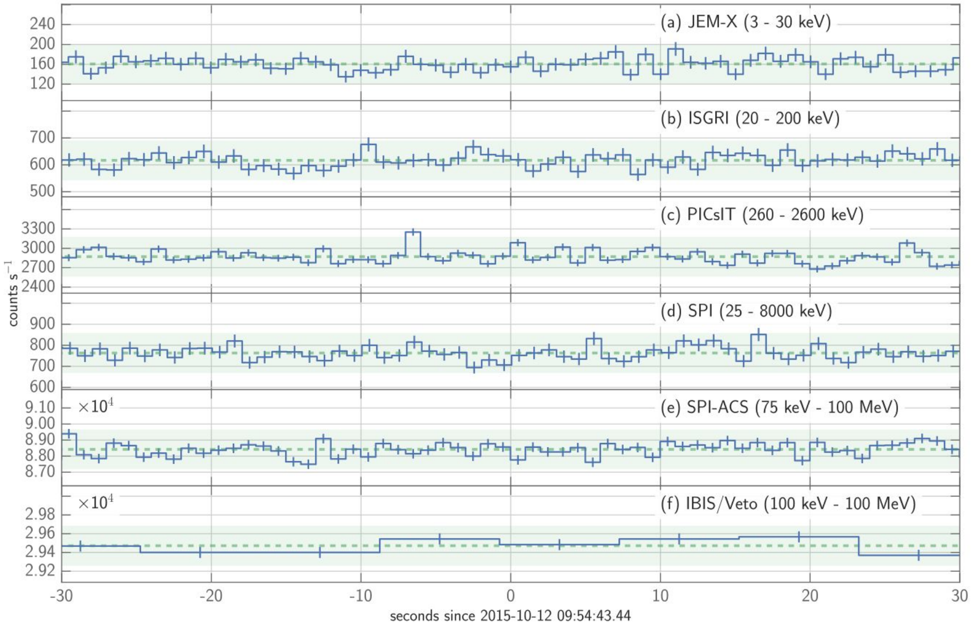
GBM-measured properties of the reported excess are not fully known - **hard to exclude.**

Intercalibration with INTEGRAL, Fermi/GBM and Konus-Wind is progressing, the stability and consistency has been proven for bright-to-medium events.

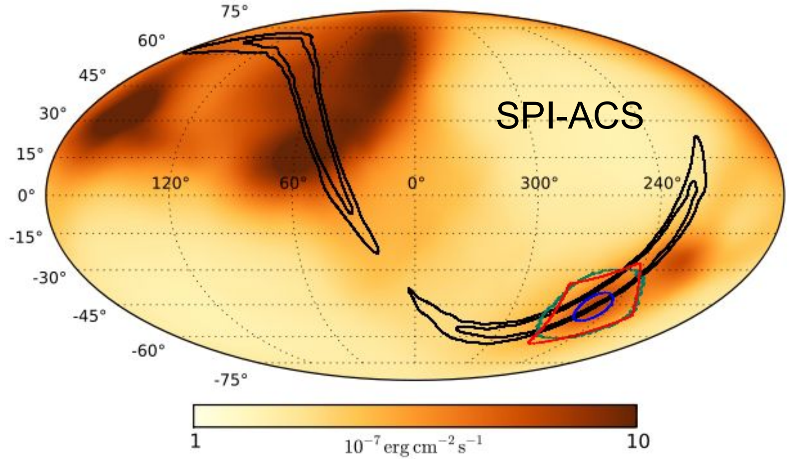
Principal activity now is learning how to compare very weak bursts.

LVT151012: SNR of 9.6, FAP of 2%

Rare lucky case: peak of the localization is in the FoV



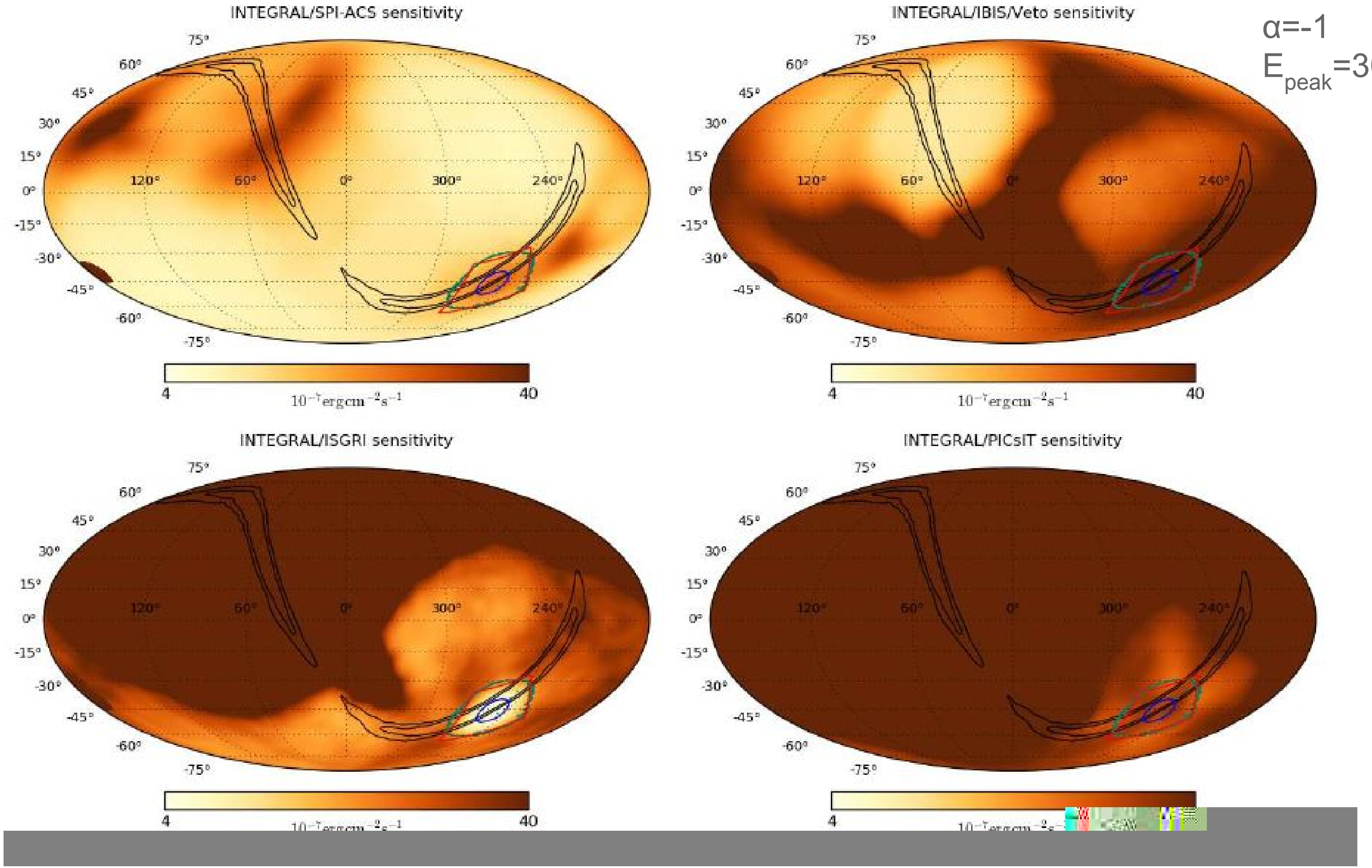
1 second, α=-0.5, E_{peak}=600 keV



Depending on the true source location, spectrum, and duration, the best limit may come from SPI-ACS, IBIS/Veto, ISGRI, PICsIT, SPI, or JEM-X…. Lucky?..

LVT151012: complicated case: all-sky

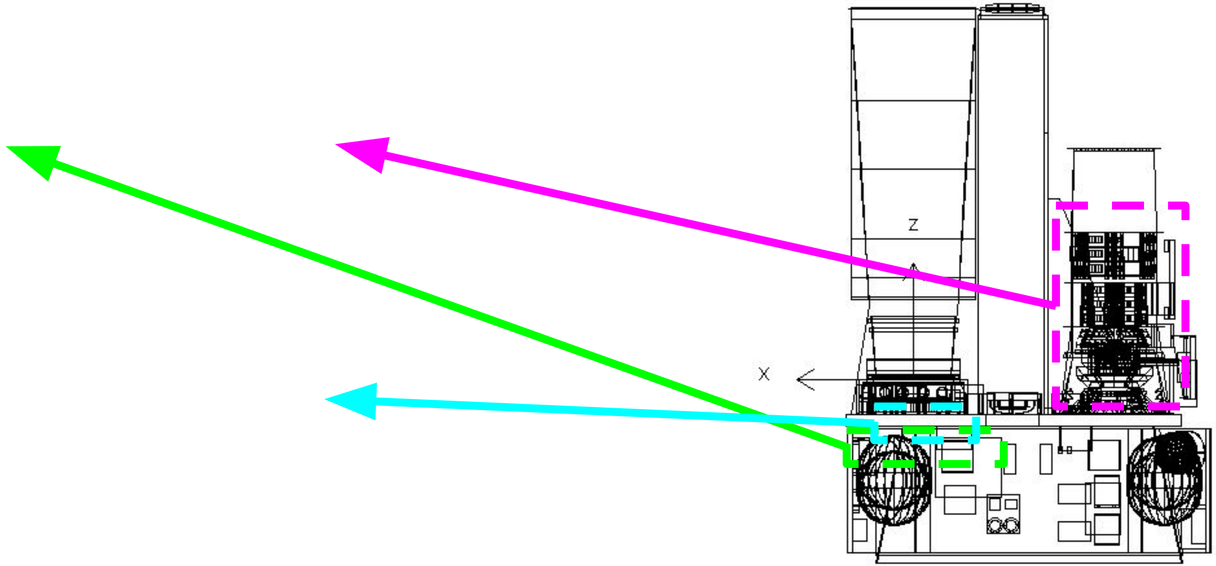
In 8 seconds
α=-1
E_{peak}=300 keV



Relative contribution of PICsIT and ISGRI reverses for very hard bursts

LVT151012: complicated case: all-sky

In 8 seconds



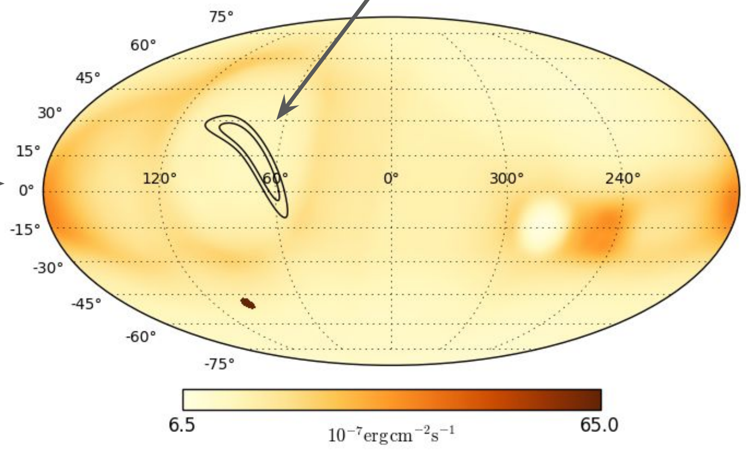
Total sensitivity is within 30% from the best in 95% of the sky, SPI-ACS only - in 75%

All-sky localization

synthetic NS merger event at 200 Mpc, what could be expected of **LVT170225, LVT170227**

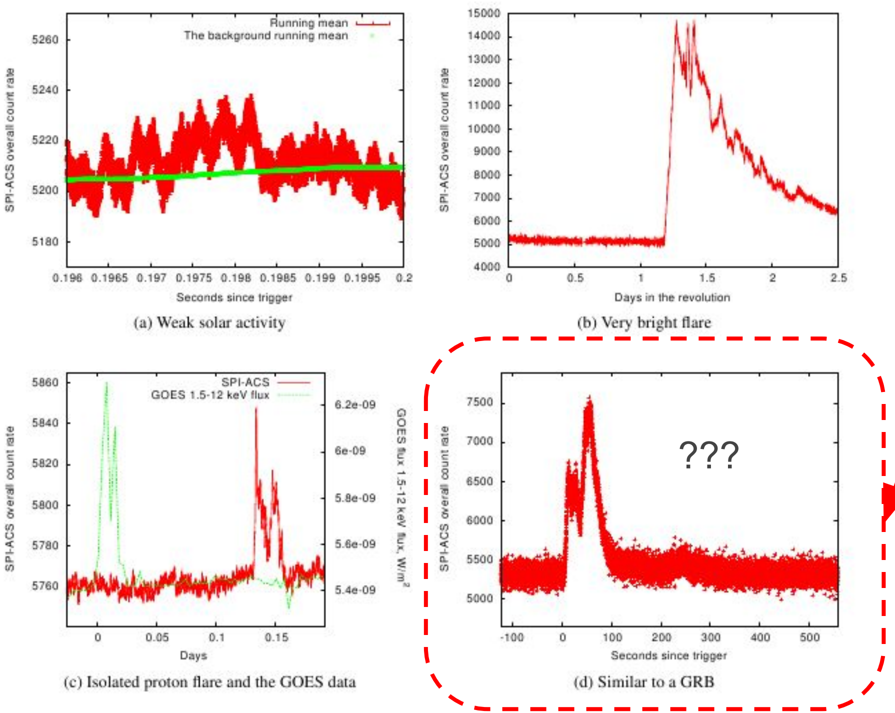
LIGO localization

INTEGRAL + LIGO localization



INTEGRAL localization

Background: solar activity: multidetector



rarely isolated flares could not be independently distinguished by SPI-ACS alone from the cosmic bursts due to lack of spectral and location characterization.

Using all INTEGRAL detectors, the events can be more efficiently classified, improving the detection performance.

SPI and JEM-X, sensitive to X-ray and gamma-ray transients only from the FoV, allow to pinpoint background variations caused by particles.

VS12

All-sky localization

INTEGRAL localization

LIGO localization

synthetic NS merger event at 200 Mpc, what could be expected of LVT170225, LVT170227

Location dependency of the INTEGRAL detector response is complex: but since it is understood, it can be used to derive **localization patterns with precise features**.

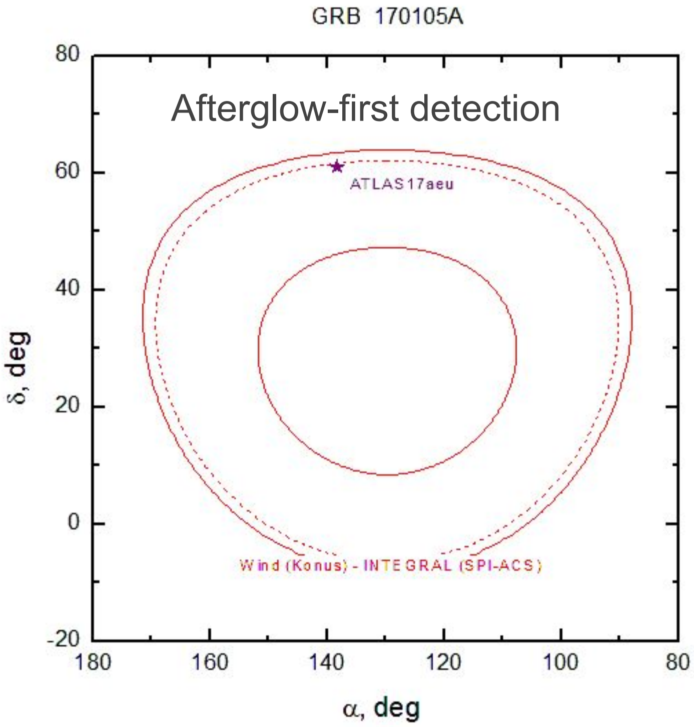
In principle similar technique is employed by the Fermi/GBM. However GBM itself is much smaller and attenuated strongly by the large body of LAT.

Konus-Wind is optimized for all-sky coverage: it measures the spectra independently on location, but also is unable to provide any localization.

For INTEGRAL, measurement of the spectrum is correlated with the location, hence it can benefit from independent measurement of the spectrum.

Multi-mission localization: ongoing

Inter-Planetary Network localizes GRBs similarly to LIGO: by measuring the difference in the arrival time - relying on accurate timing. Often it is the only source of transient location.



Unlike LIGO, currently the IPN does not take into account the intensity response information, which would allow to improve localization substantially.

This is comes as natural benefit of the intercalibration activities.

Right now a number INTEGRAL, Konus-Wind, Fermi/GBM, AstroSAT, POLAR. CALET,

INTEGRAL SPI-ACS public data service

In 2011, a public service was set up to promptly provide SPI-ACS data with the best timing accuracy

It was extensively used for years by IPN and Konus colleagues

Since 2015, Fermi/GBM team used the service to verify their detections and challenge SPI-ACS

Several other groups started to use it. In total >100 Gb has been served.

IPN format SPI-ACS light curve	2008-03-19T06:12:46 200	Submit
IPN format INTEGRAL ephemeris	2008-03-19T06:12:46	Submit
Plot SPI-ACS light curve	2008-03-19T06:12:46 200	Submit
INTEGRAL Attitude	2008-03-19T06:12:46	Submit
INTEGRAL HK light curves	SPI_VETOGATE 2008-03-19	Submit

Try using the script to access the lightcurves

RESTful service, providing various public INTEGRAL data as well as auxiliary information

More data availability

This page contains the list of triggers collected from the GCN notices (Swift and Fermi) and circulars.
For every event the link to the IPN-styled **INTEGRAL/SPI-ACS** lightcurve and the **plot** are provided.
The page is updated about every 2 minutes.
The SPI-ACS data accessible through this page is available with the delay of couple of hours after the observation.

To access the SPI-ACS data and ephemeries for any time interval, consider using use this

Two the rightmost columns can be used for the *indication for the detection in SPI-ACS* and contain the background null-hypothesis probability and number of independently detected components, correspondingly.

For questions please contact Volodymyr Savchenko

IJD	revolution	UTC	duration	messages		links		detection		spike	duration	maxsig
4492.63652991	1162.23	2012-04-19T15:15:30		3	acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.56883315	1162.21	2012-04-19T13:38:01		3	acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.53994426	1162.2	2012-04-19T12:56:25	20.0s	2	GCNs 1 acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.52592806	1162.2	2012-04-19T12:36:14		2	acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.50296509	1162.19	2012-04-19T12:03:10		2	acsisdc	IPN(plot)	Ephs	5.5123e-47	0	1.3152e-09		
4490.97154148	1161.68	2012-04-17T23:17:55		4	acsisdc	IPN(plot)	Ephs	3.5016e-218	0	0.59038		
4488.95862632	1161	2012-04-15T22:59:19.13		3	fermi-online	IPN(plot)	Ephs	undef	0	undef		
4488.89221278	1160.98	2012-04-15T21:23:41		5	acsisdc fermi-online	IPN(plot)	Ephs	undef	0	8.2453e-05		
4488.07712019	1160.71	2012-04-15T01:49:57		4	acsisdc fermi-online	IPN(plot)	Ephs	8.8213e-07	0	0.28213	2.625	7.619
4486.08876359	1160.04	2012-04-13T02:06:42.99		1	fermi-online	IPN(plot)	Ephs	undef	0	undef		
4485.92067991	1159.99	2012-04-12T22:04:40.56		3	fermi-online	IPN(plot)	Ephs	undef	0	undef		
4484.92605537	1159.65	2012-04-11T22:12:25		6	acsisdc fermi-online	IPN(plot)	Ephs	1.0886e-50	0	1.8564e-31	14.38	14.94
4484.05399461	1159.36	2012-04-11T01:16:38.95		3	swift-online	IPN(plot)	Ephs	0.56771	0	0.75175		
4483.96503905	1159.33	2012-04-10T23:08:33.19		2	swift-online	IPN(plot)	Ephs	0.015512	0	0.047187		
4483.75067238	1159.26	2012-04-10T17:59:51.91		3	swift-online	IPN(plot)	Ephs	0.47442	0	0.82333		
4483.61917007	1159.22	2012-04-10T14:50:30.11		2	fermi-online	IPN(plot)	Ephs	0.10585	0	0.91939		
4483.58548824	1159.21	2012-04-10T14:02:00		5	acsisdc fermi-online	IPN(plot)	Ephs	5.3387e-21	0	0.18955	0.175	20.62

SPI-ACS direct access to the data

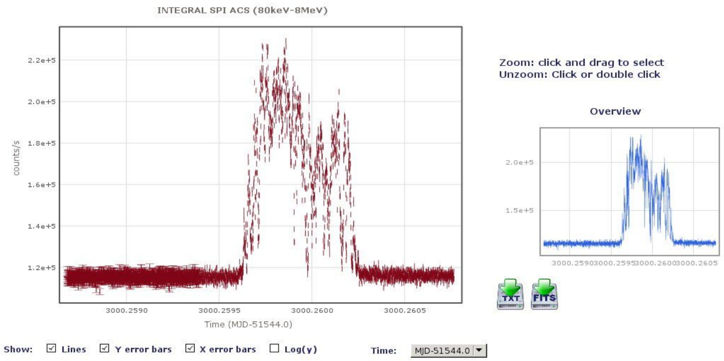
Light curves	both NRT and Archived, available with a delay of few hours. *Now in the IPN format*
Ephemeries	INTEGRAL ephemeries
Attitude	and Ecliptic to satellite coordinates convertion
Triggers	Links to the ACS lightcurves for a list of external triggers

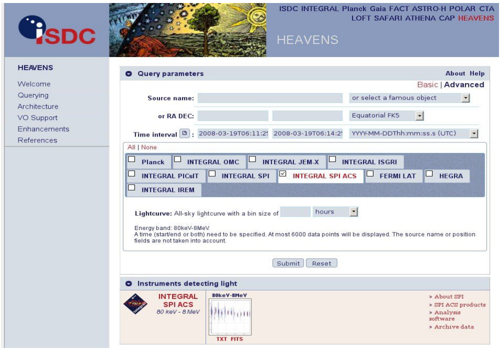
Try using the script to access the lightcurves

For the realtime triggers and overall list of the triggers give a look to ACS triggers page at ISDC

For a nice online graphical interface to SPI-ACS light curves (and much more) check out the HEAVENS (though, do not search there for the most recent ones)

If in doubt contact me

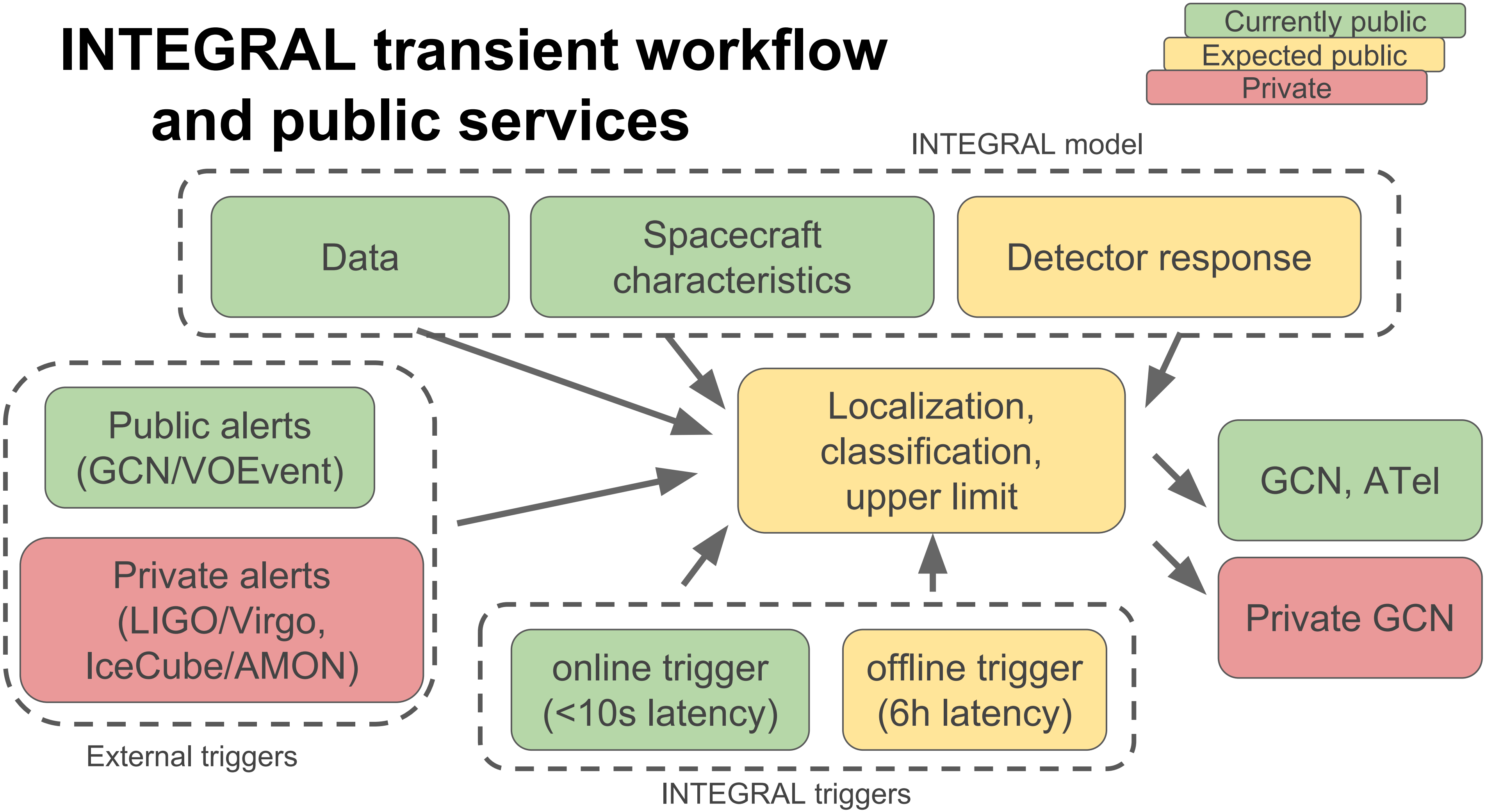




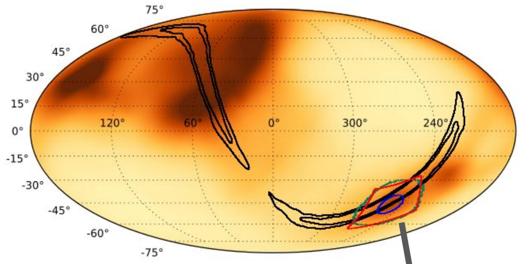
Near realtime data interface, for prompt reaction on the astrophysical events

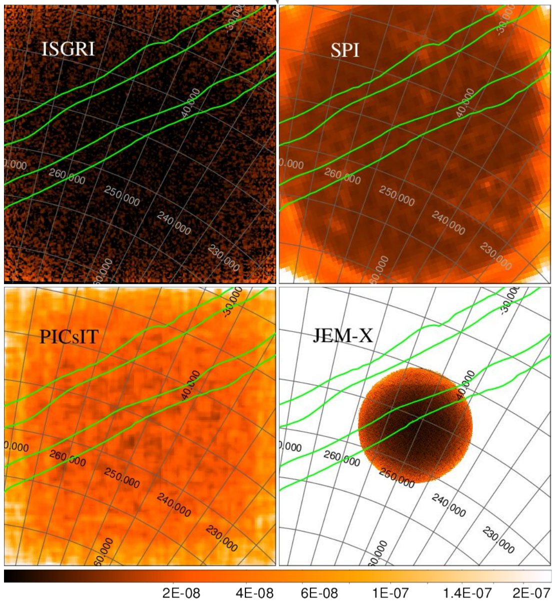
Data for the HEAVENS, to be explored in the frame of the rich data base

INTEGRAL transient workflow and public services

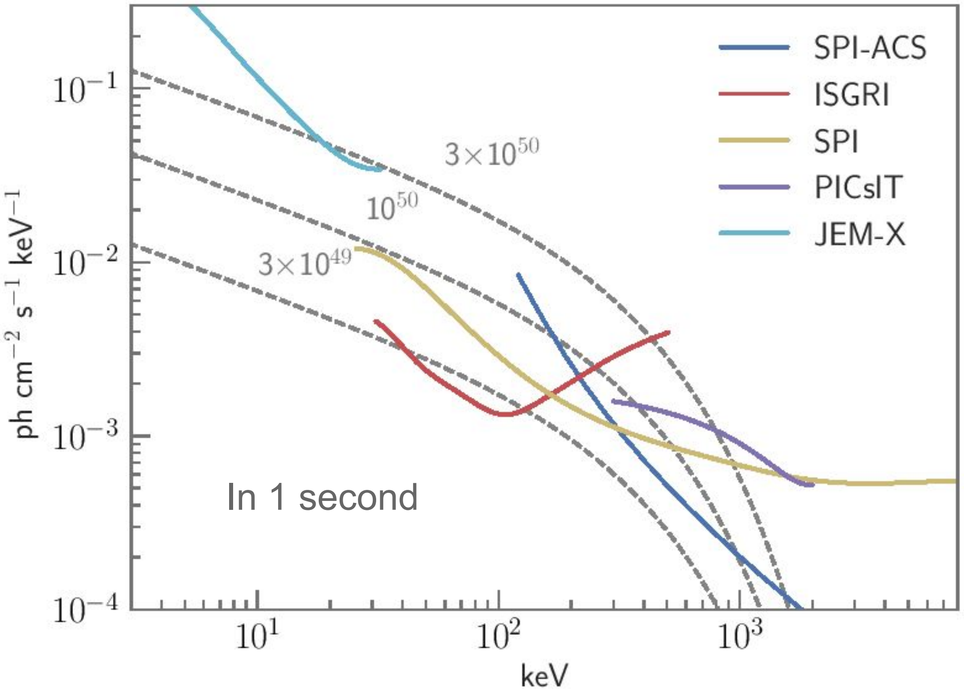


LVT151012: Field of View



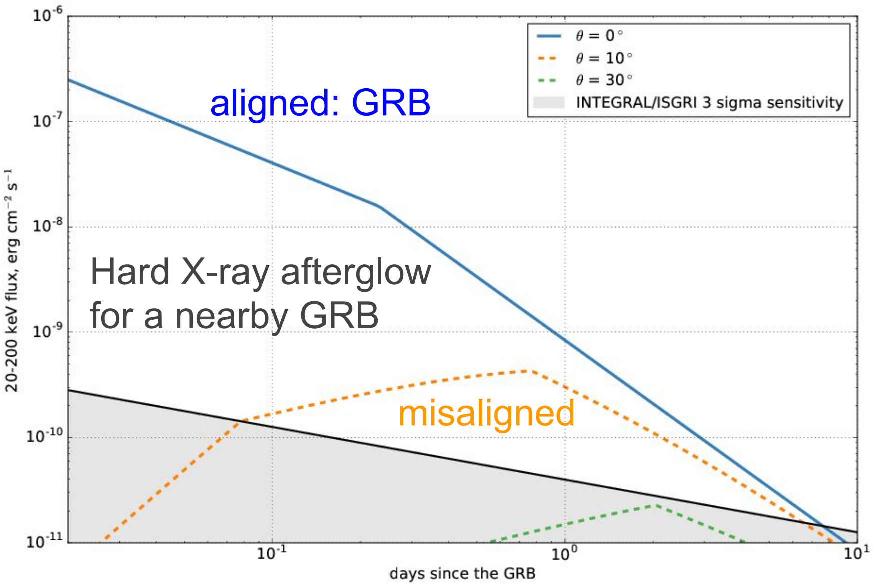


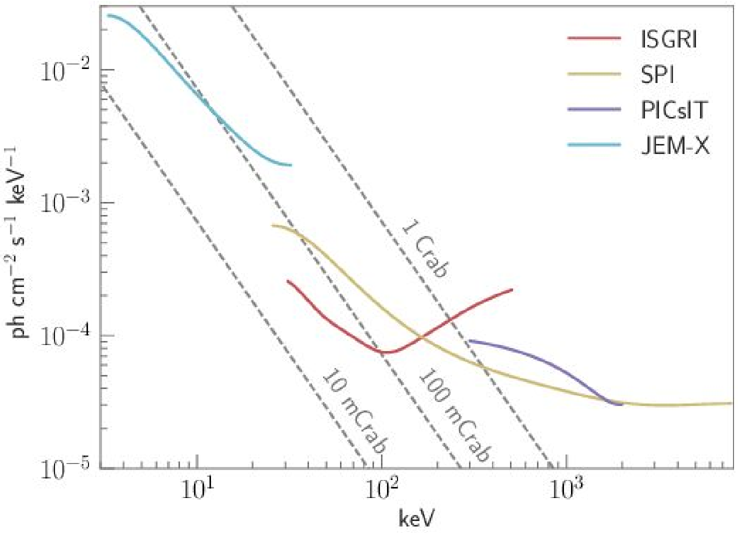
In ~300 seconds



Up to 20% of the localization is in the FoV,
3 orders of magnitude in energy covered.

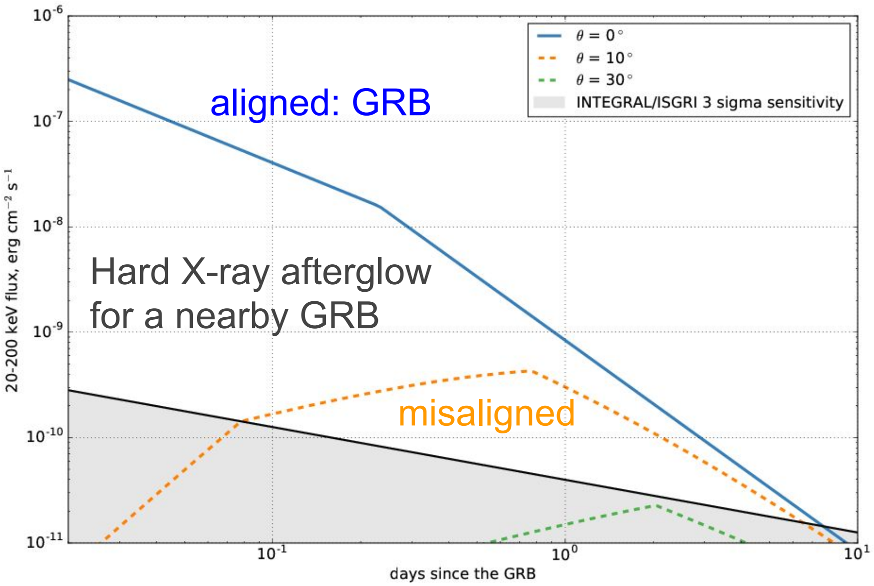
Perspectives for pointed follow-up

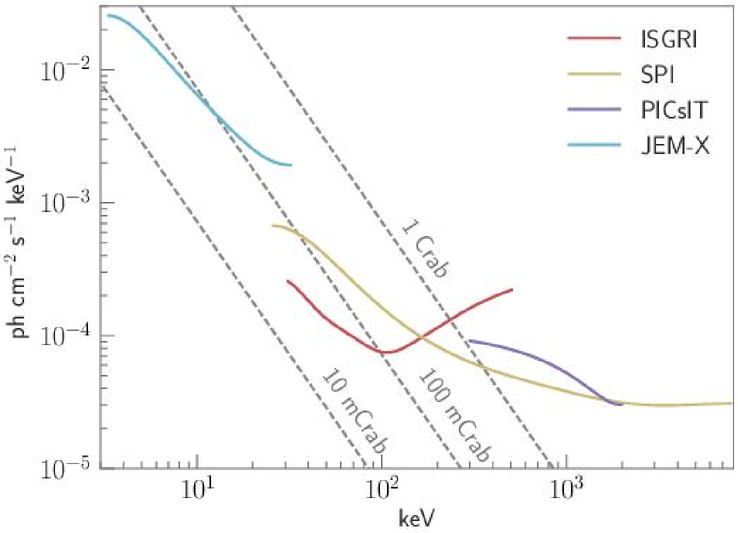




Off-axis afterglow at the distance of LVT151012, prediction based on actual hard X-ray afterglow (Martin-Carillo 2014) and a simple deccelerating jet model (Granot et al 2002)

Perspectives for pointed follow-up



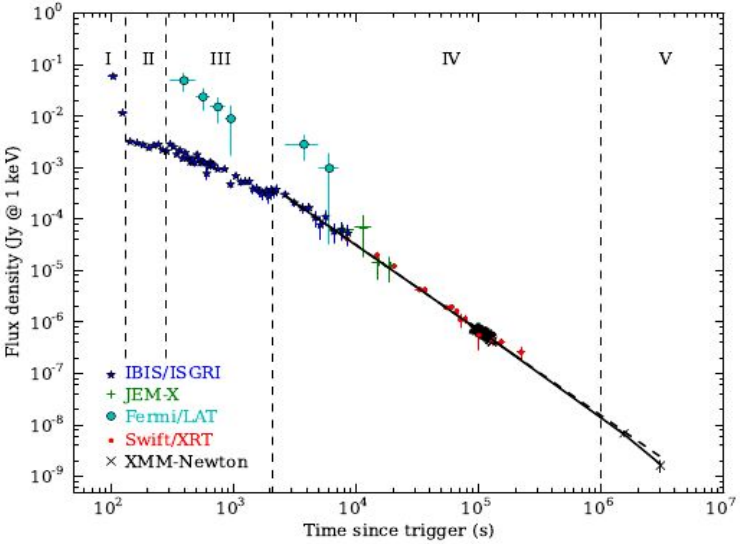


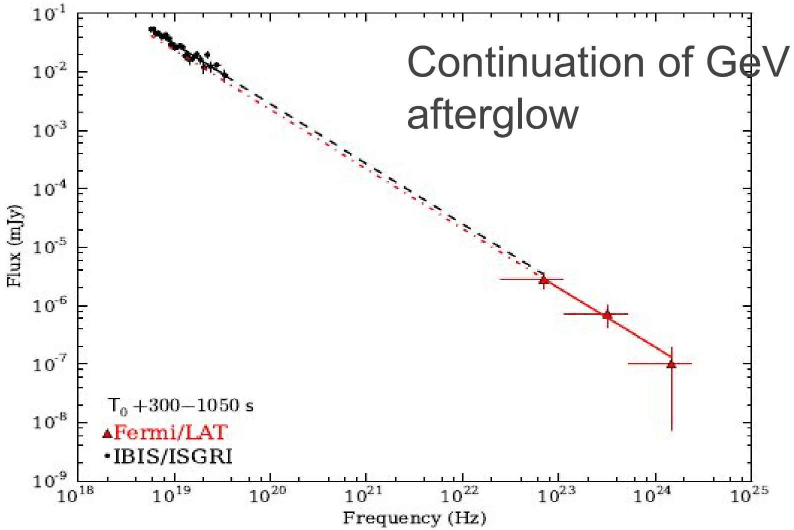
Fast ToO observations are very benefitial to achieve the detection

Fast ToO observations of known bright GRBs would be very useful to further the possibility of very long HXR afterglows

Perspectives for pointed follow-up: GRB120711A

Luminous GeV-loud GRB happened in ISGRI FoV (1 in 10 years chance)





Martin-Carillo 2014

Hard X-ray emission has been observed above 20 keV for 20000 seconds

Hard X-ray afterglow is also seen in GRB130427A, GRB080319B, and few more

Conclusions and outlook

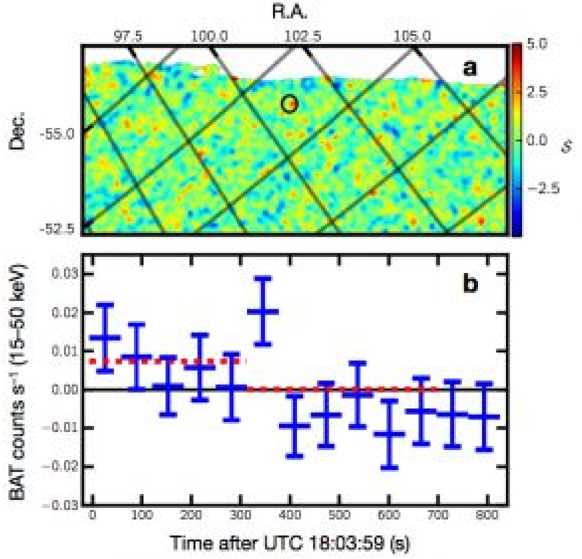
- INTEGRAL strengths in observations of GRB-like transients:
  - high duty cycle, uninterrupted 2-day long observations in stable background
  - competitive all-sky sensitivity, down to 10^{-7} erg cm^{-2} s^{-1} (75 - 2000 keV) with complementary role of every instrument
- A secure binary NS detection in O2 still not guaranteed or even expected, but it is the right time to be ready
- We also perform **neutrino follow-up**, including the privately distributed multiplets, same procedure was applied to **FRB**, constraining the Swift/BAT detection
- In-depth in-flight calibration that was required for INTEGRAL all-sky response opens new inter-mission possibilities, not previously accessible
- Studying shadows on IBIS detector shadows and Compton imaging are capable of providing more accurate imaging
- Very **fast ToO** observations would be **incredibly useful**

Conclusions and outlook

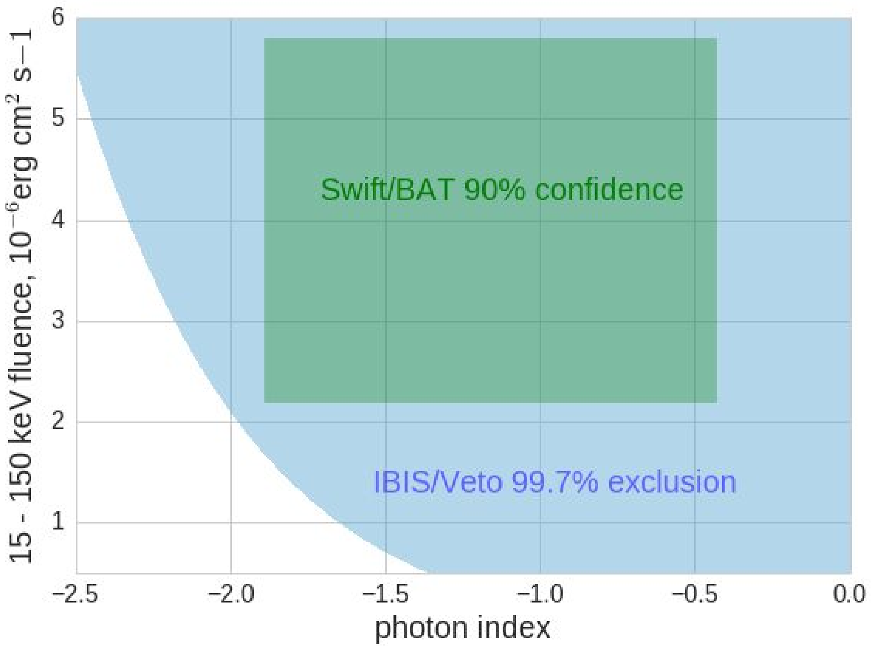
- Further

Swift counterpart to FRB131104

Swift/BAT image



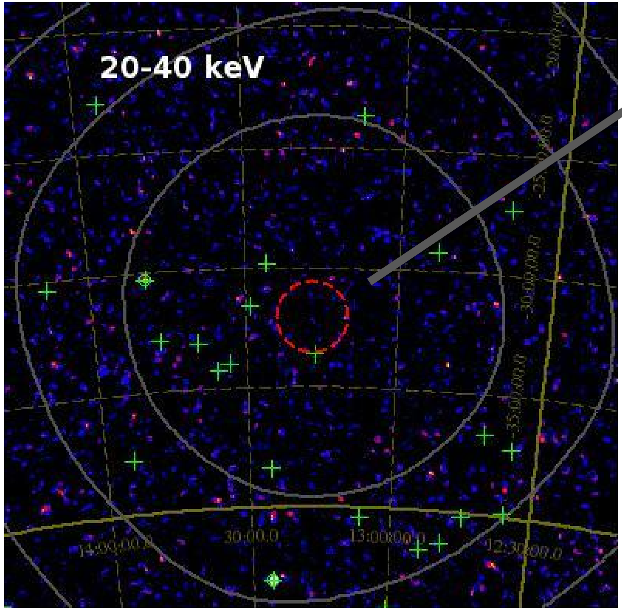
DeLaunay 2016

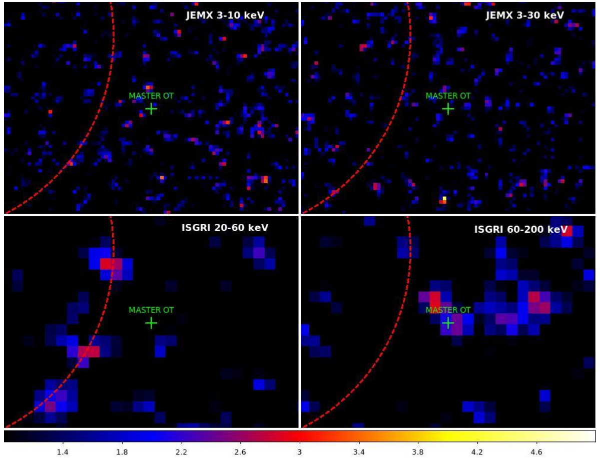


"Given its duration (T90 > 100 s), its spectrum, and the absence of a BAT trigger, non-detections of the source by the Fermi GBM, INTEGRAL SPI-ACS, Konus-Wind, and other Interplanetary Network detectors are not further constraining of the counterpart's gamma-ray properties." - **not true!**

Neutrinos follow-up

INTEGRAL also recently made an agreement with IceCube to follow-up high-energy neutrino events.





Pointed follow-up of an IceCube event, for the same event an optical transient was reported by MASTER